Whitespace Evaluation SofTware (WEST) and its applications to whitespace in Canada and Australia

Kate Harrison, Vidya Muthukumar, and Anant Sahai
UC Berkeley
Whitespaces are gaining momentum

US 5 GHz NPRM
April 2014
Whitespaces are gaining momentum

US 5 GHz NPRM
April 2014

Singapore TVWS
June 2014
Whitespaces are gaining momentum

US 5 GHz NPRM
April 2014

Singapore TVWS
June 2014

Canada TVWS
February 2015
Whitespaces are gaining momentum

US 5 GHz NPRM
April 2014

Singapore TVWS
June 2014

Canada TVWS
February 2015

US 3.5 GHz
April 2015
Whitespaces are gaining momentum

US 5 GHz NPRM
April 2014

Singapore TVWS
June 2014

Canada TVWS
February 2015

US 3.5 GHz
April 2015

US TVWS rule update
August 2015
How do we quantify whitespaces?
How do we quantify whitespaces?

<table>
<thead>
<tr>
<th>Market</th>
<th>No. of Vacant Channels Between Chs. 2-51 After DTV Transition</th>
<th>Percent of TV Band Spectrum Vacant After DTV Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juneau, Alaska</td>
<td>37</td>
<td>74%</td>
</tr>
<tr>
<td>Honolulu, Hawaii</td>
<td>31</td>
<td>62%</td>
</tr>
<tr>
<td>Phoenix, Arizona</td>
<td>22</td>
<td>44%</td>
</tr>
<tr>
<td>Charleston, West Virginia</td>
<td>36</td>
<td>72%</td>
</tr>
<tr>
<td>Helena, Montana</td>
<td>31</td>
<td>62%</td>
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<tr>
<td>Boston, Massachusetts</td>
<td>19</td>
<td>38%</td>
</tr>
<tr>
<td>Jackson, Mississippi</td>
<td>30</td>
<td>60%</td>
</tr>
<tr>
<td>Fargo, North Dakota</td>
<td>41</td>
<td>82%</td>
</tr>
<tr>
<td>Dallas-Ft. Worth, Texas</td>
<td>20</td>
<td>40%</td>
</tr>
<tr>
<td>San Francisco, California</td>
<td>19</td>
<td>37%</td>
</tr>
<tr>
<td>Portland, Maine</td>
<td>33</td>
<td>66%</td>
</tr>
<tr>
<td>Tallahassee, Florida</td>
<td>31</td>
<td>62%</td>
</tr>
<tr>
<td>Portland, Oregon</td>
<td>29</td>
<td>38%</td>
</tr>
<tr>
<td>Seattle, Washington</td>
<td>26</td>
<td>52%</td>
</tr>
<tr>
<td>Las Vegas, Nevada</td>
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<td>52%</td>
</tr>
<tr>
<td>Trenton, New Jersey</td>
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<td>30%</td>
</tr>
<tr>
<td>Richmond, Virginia</td>
<td>32</td>
<td>64%</td>
</tr>
<tr>
<td>Omaha, Nebraska</td>
<td>26</td>
<td>52%</td>
</tr>
<tr>
<td>Manchester, New Hampshire</td>
<td>23</td>
<td>46%</td>
</tr>
<tr>
<td>Little Rock, Arkansas</td>
<td>30</td>
<td>60%</td>
</tr>
<tr>
<td>Columbia, South Carolina</td>
<td>35</td>
<td>70%</td>
</tr>
<tr>
<td>Baton Rouge, Louisiana</td>
<td>22</td>
<td>44%</td>
</tr>
</tbody>
</table>
Whitespace maps
How do we quantify whitespaces?

“Aggregate interference with FCC and ECC white space usage rules: case study in Finland” (Jäntti, et al. 2011)
How do we quantify whitespaces?

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"UHF white space in Europe — A quantitative study into the potential of the 470–790 MHz band" (Beek, et al. 2011)
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Ofcom 2013 consultation
How do we quantify whitespaces?

“Aggregate interference with FCC and ECC white space usage rules: case study in Finland” (Jäntti, et al. 2011)

“UHF white space in Europe — A quantitative study into the potential of the 470–790 MHz band” (Beek, et al. 2011)

“Opportunities for white space usage in Australia”
Freyens and Loney, 2011
Making it easier to quantify whitespaces
Motivating example

Public Policy + AM/FM whitespace → FCC
Motivating example

- Easy to use
- Free
- Reliable
- Flexible/extensible
Existing tools
Existing tools

- Many tunable parameters
- Written in Matlab

“Software Tool for Assessing Secondary System Opportunities in Spectrum Whitespaces” (WoWMoM 2013)
Existing tools

- Many tunable parameters
- Written in Matlab
- Not available for public use

“Software Tool for Assessing Secondary System Opportunities in Spectrum Whitespaces” (WoWMoM 2013)
WEST
(Whitespace Evaluation SofTware)

Written in...

Posted on...

west.kateharrison.net
Key features

- Extensible to other bands
- Free, easier to integrate (e.g. AWS)
- Modular, extensible
- Open-source with GPLv2
The real test

WEST + first year grad student = 2 papers

Whitespaces after the USA’s TV incentive auction: a spectrum reallocation case study
Vidyia Muthukumar, Angel Daruna, Vijay Kamble, Kate Harrison, and Anant Sahai
Wireless Foundations, EECS, UC Berkeley

Abstract—Spectrum has traditionally been allocated for single uses and now most of the “prime” spectrum has well-established incumbent users. When a new service needs spectrum, there are two qualitatively distinct ways of making bandwidth available for it: (a) a swath of incumbent users can be removed from a band, with the cleared band being reallocated for the new service. Alternatively, the new users can be allowed to utilize the interstitial spectrum holes (i.e., whitespaces) between incumbent users, with the requirement to protect the incumbents’ QoS. But these can also be used in combination by partially clearing a band and opening up the rest for whitespaces-style sharing. In this case, the ability of regulating to “regulate” incumbents, e.g., after their operating channels, is not the need to reallocate them. An open question is how to ensure that incumbent users can re-use their interstitial spectrum holes and that new entrants interact with each other and the ability to re-occupy whitespacing. Do efficient whitespaces completely eliminate whitespace problem?

The USA FCC’s ongoing incentive auction in the TV bands is the first large-scale attempt to reallocate a major band of spectrum in order to clear spectrum for LTE. This auction is meant to navigate the tradeoff between incumbent TV services and LTE networks. In preparation, the FCC has made a large and complex dataset of reoccupying constraints available for the first time. We have reprocessed this data and built our own re-occupying engine in order to study a more general version of the tradeoff between whitespaces and cleared spectrum.

We conclude that (1) reoccupying enables clearing of significantly more whitespace than can be cleared with incumats. (2) the total amount of spectrum available for LTE is relatively insensitive to how incumats are removed. (3) efficient reoccupying biases towards tradwhitespace for cleared spectral holes; (4) even the most efficient reoccupying has plenty of whitespace — an amount that can be comparable with the amount of cleared spectrum.

I. INTRODUCTION

TV spectrum has recently become a very popular topic due to its proximity to mobile spectrum as well as the TV whitespaces, which give access to spectrum necessary for economic development. There are many interesting aspects to the field of cognitive radio and whitespaces, such as coexistence techniques, network planning, system architecture, and security and robustness, whose unique challenges have been studied to varying degrees. However, few studies address a very simple question: when is it better to completely reallocate a band vs. to share it?

In fact, there are several different options for making “new” spectrum, as shown in Figure 1:

1) Completely reallocate the band as a single-use band.

2) Declare the entire band potential whitespace while preserving the quality-of-service of the incumbent via sharing rules. This is becoming the de facto way of “generating” new spectrum, especially after the publication of the PCAST report [1]. Whitespaces regulations naturally have to navigate a tradeoff between quality-of-service for the incumbent users, the secondary users. This has been explored in [2]-[4].

3) Partial clearing of the band. Passive spectrum is created while a portion of the incumbent remains.

4) Efficient partial clearing of the band. The spirit and use cases are very similar to scenario 3 except that this option maximizes the number of incumbents that remain after a partial clearing. Rather than remove the incumbents which were in the new-cleared spectrum, these incumbents are efficiently packed into the remaining (unallocated) spectrum whenever possible. This approach essentially sacrifices whitespace in order to accommodate new services.

Fig. 1. An illustration of the various options for spectrum repurposing. Incumats are shown as gray dots while whitespaces on blue and cleared spectrum is green. White represents unused spectrum in the case of whitespaces. In a case where the QoS of the incumbent is critical, the secondary users are represented by a yellow and black band; this represents a fair tradeshow that could also support whitespace rules.

This report, scheduled as a recommendation to the President of the United States by the President’s Council of Advisors on Science and Technology in 2010 [1], has generated significant efforts to develop new rules that allow spectrum to be shared within the constraints that were set by the FCC. These rules have been designed to protect incumbents from interference while allowing secondary users to use the spectrum for their own purposes. The success of these rules has been evaluated through various experiments and simulations, and it has been shown that they can effectively share spectrum while maintaining QoS for both incumbent and secondary users.

In conclusion, we have explored the different options for making “new” spectrum and have shown that a large fraction of allocated spectrum actually lays fallow. Since it is not practical to make sweeping changes to existing allocations and deployments, dynamic spectrum access (DSA) is critical for harnessing this spectrum that is already used but underutilized.

Whitespace Evaluation Software (WEST) and its applications to whitespace in Canada and Australia
Kate Harrison, Vidyia Muthukumar, and Anant Sahai
Wireless Foundations, EECS, UC Berkeley

Abstract—Spectrum whitespaces and dynamic spectrum sharing have become important and interesting topics in recent years. The USA authorized the use of TV whitespaces in 2002 and the UK and Canada followed suit in early 2015. In light of the PCAST report of 2012, additional bands are being evaluated for spectrum sharing in the USA and abroad.

With the increasing number of spectrum whitespaces, it is more important than ever to understand the consequences of regulatory decisions. For example, what is the effect of increasing the separation distance from 1km to 1.5km? Regulations need to be designed to avoid such decisions that favor one product over another.

Despite the clear need for data-driven analyses to appear to be quite rare among regulators, industry members, and researchers alike.

Although the data is often freely available, employing it can be an onerous task. In order to reduce this barrier, we have created an open-source software package, WEST, that quickly allows a user to estimate the amount of whitespace in a given region.

For example, after collecting the requisite data, we produced estimates of the amount of whitespace in Canada and under an assumption. To demonstrate the power of our software, we present novel results on whitespace availability in Canada and Australia.

However, the true potential of WEST lies in the ability to configure it to use existing or hypothetical auctions. We use WEST to compare the FCC and Industry Canada (IC) rulesets, showing that the latter loses approximately one whitespace channel, mainly due to the increased size of IC’s separation distance as compared to the FCC’s. We also showed that although the effect of labes channel exclusion (a notion introduced in the IC report) is similar in Canada, it would be much larger if applied to the USA. The identifications of the real-world effects of these regulatory decisions was made possible by the ability to create “chimera rulesets,” i.e. monads of the IC and FCC rules, so that we could examine each variable in isolation.

Finally, we describe the high-level design of WEST. The modular design makes it easy for users to combine, replace, modify, or remove various components to achieve the desired effect. We sincerely hope that the community will use and contribute to WEST, turning it into an even more powerful tool than it is today. If real-world data are at your fingertips and easy to use, what would you do?
Using WEST to study...

- Whitespaces in Canada
- Differences between FCC and Industry Canada ruleset
- Whitespaces in Australia
- Amount of contiguous-channel whitespace
Existing results:
Whitespaces in USA

Urban areas — sparse in whitespace
Rural areas — abundant in whitespace
Applications of WEST:
Whitespaces in Canada (under the FCC ruleset)
Applications of WEST:
Whitespaces in Canada (under the FCC ruleset)
Applications of WEST: Whitespaces in Canada (under the FCC ruleset)
Applications of WEST:
Whitespaces in Canada (under the FCC ruleset)

“Equal weight” map
Applications of WEST: Whitespaces in Canada (under the FCC ruleset)

“Equal weight” map

Canada has more WS by area
Applications of WEST:
Whitespaces in Canada (under the FCC ruleset)

“Equal weight” map

Canada has more WS by area
Applications of WEST:
Whitespaces in Canada (under the FCC ruleset)

“Equal weight” map

Canada has more WS by area
Applications of WEST: Whitespaces in Canada (under the FCC ruleset)

“Equal weight” map

Population map

Canada has more WS by area
Applications of WEST: Whitespaces in Canada (under the FCC ruleset)

Canada has more WS by area

USA has more WS by population
Applications of WEST:
Whitespaces in Canada (under the FCC ruleset)

Canada has more WS by area
USA has more WS by population
Applications of WEST: Whitespaces in Canada (under the FCC ruleset)

- Canada has more WS by area
- USA has more WS by population

“Equal weight” map

Population map
Applications of WEST:
Whitespaces in Canada (under the FCC ruleset)
Applications of WEST:
Whitespaces in Canada (under the FCC ruleset)

- Part 1: Importing data (2 hrs, ~200 lines of code)

- Part 2: Evaluating WS (~7 lines of code)
Applications of WEST:
Whitespaces in Canada (under the FCC ruleset)

- **Part 1: Importing data** (2 hrs, ~200 lines of code)
  - Boundary file (.SHP file), readable by WEST

- **Part 2: Evaluating WS** (~7 lines of code)
Applications of WEST:
Whitespaces in Canada (under the FCC ruleset)

- **Part 1: Importing data** (2 hrs, ~200 lines of code)
  - Boundary file (.SHP file), readable by WEST
  - Listing of Canada TV Stations

- **Part 2: Evaluating WS** (~7 lines of code)
  - TV station
    - Location
    - Call sign
    - Height
    - Tx type (D/A)
    - Frequency
    - Tx power
Applications of WEST: Whitespaces in Australia

- Procedure similar to Canadian exercise
- Whitespace evaluated under FCC ruleset

- WS in Australia more plentiful (some channels are vacant)
- No candidate ruleset yet
Industry Canada (IC) ruleset, released early 2015
How does it compare with FCC’s ruleset?
The FCC Ruleset
FCC vs IC: Separation Distances

*for almost all TV stations
FCC vs IC:
Separation Distances

Increased separation distances*

*for almost all TV stations
FCC vs IC: Protected Contour Definition

Spatial buffer

TV station

Protected TV receivers

Transmitting secondaries

Different protected contour
FCC vs IC: Protected Contour Definition

- TV station
- Transmitting secondaries
- Protected TV receivers
- Spatial buffer

implies more protection
FCC vs IC: Protected Contour Definition
FCC vs IC: Protected Contour Definition

(depending on frequency of channel)
FCC vs IC: Taboo Channels

- Upper freq. buffer zone
- Primary's service area
- Spatial buffer zone
- Lower freq. buffer zone

Frequency:
- C
- C+1

Space:
- C-1
FCC vs IC: Taboo Channels

- **Frequency Space**
  - C+3
  - C+2
  - C+1
  - C
  - C-1
  - C-2
  - C-3

- **Upper freq. buffer zones**
- **Primary’s service area**
- **Spatial buffer zone**
- **Lower freq. buffer zones**
Whitespaces in Canada — under the FCC ruleset

FCC ruleset
Whitespaces in Canada — under the Industry Canada ruleset
Whitespaces in Canada — under the Industry Canada ruleset
FCC vs IC: Chimera Rulesets
FCC vs IC: Chimera Rulesets
FCC vs IC: Chimera Rulesets

FCC ruleset

Changed protected contour radii
FCC vs IC: 
Chimera Rulesets

FCC ruleset
- Changed protected contour radii

→ Chimera ruleset 1
FCC vs IC: Chimera Rule sets

FCC ruleset → Chimera ruleset 1

- Changed protected contour radii
- Increased separation distances
FCC vs IC: Chimera Rulesets

- FCC ruleset
  - Changed protected contour radii

  - Chimera ruleset 1
    - Increased separation distances

  - Chimera ruleset 2
FCC vs IC: Chimera Rulesets

FCC ruleset → Chimera ruleset 1 → Chimera ruleset 2

- Changed protected contour radii
- Increased separation distances
- Added taboo channel exclusions
FCC vs IC: Chimera Rulesets

FCC ruleset → Chimera ruleset 1 (changed protected contour radii) → Chimera ruleset 2 (increased separation distances) → Chimera ruleset 3 (added taboo channel exclusions)
FCC vs IC: Chimera Rulesets

- FCC ruleset
  - Changed protected contour radii

  Chimera ruleset 1
  - Increased separation distances

  Chimera ruleset 2
  - Added taboo channel exclusions

  Chimera ruleset 3
  - Added far-side separation distances
FCC vs IC: Chimera Rulesets

**FCC ruleset**
- Changed protected contour radii

**Chimera ruleset 1**
- Increased separation distances

**Chimera ruleset 2**
- Added taboo channel exclusions

**Chimera ruleset 3**
- Added far-side separation distances

**IC ruleset**
FCC vs IC: Difference CCDFs
FCC vs IC: Difference CCDFs

1. Whitespace map under chimera ruleset 1

2. Whitespace map under chimera ruleset 2
FCC vs IC: Difference CCDFs

1. Whitespace map under chimera ruleset 1

2. Whitespace map under chimera ruleset 2
FCC vs IC:

1. Whitespace map under chimera ruleset 1
2. Whitespace map under chimera ruleset 2

Difference map

Difference CCDF
FCC vs IC: Difference CCDFs

1. Whitespace map under chimera ruleset 1
2. Whitespace map under chimera ruleset 2

Difference map
FCC vs IC: Difference CCDFs

1. Whitespace map under chimera ruleset 1

2. Whitespace map under chimera ruleset 2

Difference map

Population map
FCC vs IC: Difference CCDFs

1. Whitespace map under chimera ruleset 1

2. Whitespace map under chimera ruleset 2

Difference map

Population map

Difference CCDFs
FCC vs IC:
Difference CCDFs

1. Whitespace map under chimera ruleset 1
2. Whitespace map under chimera ruleset 2

Population map
FCC vs IC:
Difference CCDFs

1. Whitespace map under chimera ruleset 1
2. Whitespace map under chimera ruleset 2

Difference map
Population map
FCC vs IC: Results
FCC vs IC: Results

Canada
FCC vs IC: Results

Canada
FCC vs IC: Results

Canada
FCC vs IC: Results

Canada
FCC vs IC: Results

Canada

USA
FCC vs IC: Results

Canada

USA
FCC vs IC: Results

Canada

USA
FCC vs IC: Results

Canada

USA
Applications of WEST:

Contiguous channel whitespace availability

- Important for *practical implementation*

- < 50 lines of code
Applications of WEST:
Contiguous channel whitespace availability

• Important for \textit{practical implementation}

• $< 50$ lines of code
Other uses of WEST

- Comments to regulators (e.g. quantifying tradeoffs)
- Reproducible research
- New economic models
Design

Device
- Portable/fixed
- Height
- Geolocation?
Design

Device
- Portable/fixed
- Height
- Geolocation?

Region: United States
- Protected entities: TV stations
  - TV station
- Protected entities: radioastronomy sites
  - RAS site
- Protected entities: PLMRS sites
  - PLMRS site

Geographical boundary information
Potential white space channels, corresponding frequencies

DataMap2D
- Lat-long boundaries
- # latitude divisions
- # longitude divisions

Protected entities: TV stations
- Source filename
- Source format
Design

Device: fixed
Region: United States

DataMap2D
Design

Ruleset: FCC

Region: United States

Device: fixed

DataMap2D

Protection rules for TV stations
Protection rules for PLMRS sites
Protection rules for radioastronomy sites
Logic for combining protection rules
Design

Ruleset: FCC

Device: fixed

Region: United States

Channel number: 21

DataMap2D
Design

Device: fixed

Region: United States

Ruleset: FCC

Channel number: 21

DataMap2D

Whitespace channel count

Whitespace delta map

CCDFs by area, population

Pareto plots

2D histograms
Generating a whitespace map
Generating a whitespace map

from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

Load WEST modules
Generating a whitespace map

from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates,
    BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

Specify the device
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

datamap_spec = SpecificationDataMap(DataMap2DContinentalUnitedStates, 200, 300)

region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates, datamap_spec)
Generating a whitespace map

from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)
datamap_spec = SpecificationDataMap(DataMap2DContinentalUnitedStates, 200, 300)
region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates, datamap_spec)

is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec, RegionCanada, RulesetFcc2012, test_device)

is_whitespace_map = is_whitespace_map_spec.fetch_data()

generate_whitespace_map(, , , )
Generating a whitespace map

```python
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

# Define a test device

test_device = Device(is_portable=False, haat_meters=30)

datamap_spec = SpecificationDataMap(DataMap2DContinentalUnitedStates, 200, 300)

region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates, datamap_spec)

is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec, RegionCanada, RulesetFcc2012, test_device)

is_whitespace_map = is_whitespace_map_spec.fetch_data()

# Generate whitespace map

generate_whitespace_map()
```

"Specifications" are helpers that know how to generate data
Generating a [Canadian] whitespace map

```python
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryCanada
from west.region_canada import RegionCanada
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

datamap_spec = SpecificationDataMap(DataMap2DCanada, 200, 300)

region_map_spec = SpecificationRegionMap(BoundaryCanada, datamap_spec)

is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec, RegionCanada, RulesetFcc2012, test_device)

is_whitespace_map = is_whitespace_map_spec.fetch_data()
```
Generating a whitespace map

```python
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, \  
    BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

datamap_spec = SpecificationDataMap(DataMap2DContinentalUnitedStates, 200, 300)

region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates, datamap_spec)

is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec, RegionUnitedStates, RulesetFcc2012, test_device)

is_whitespace_map = is_whitespace_map_spec.fetch_data()
total_whitespace_channels = is_whitespace_map.sum_all_layers()

is_in_region_map = region_map_spec.fetch_data()
plot = total_whitespace_channels.make_map(is_in_region_map=is_in_region_map)
```
Generating a whitespace map

```python
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, 
    BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

datamap_spec = SpecificationDataMap(Region2DContinentalUnitedStates, 200, 300)

region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates, 
    datamap_spec)

is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec, 
    RegionUnitedStates, 
    RulesetFcc2012, 
    test_device)

is_whitespace_map = is_whitespace_map_spec.fetch_data()
total_whitespace_channels = is_whitespace_map.sum_all_layers()

is_in_region_map = region_map_spec.fetch_data()
plot = total_whitespace_channels.make_map(is_in_region_map=is_in_region_map)

plot.add_boundary_outlines(boundary=BoundaryContinentalUnitedStatesWithStateBoundaries())
plot.set_boundary_color('k')
plot.set_boundary_linewidth('1.0')
```

Add the state outlines (in black)
Generating a whitespace map

```python
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

datamap_spec = SpecificationDataMap(DataMap2DContinentalUnitedStates, 200, 300)

region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates, datamap_spec)

is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec, RegionUnitedStates, RulesetFcc2012, test_device)

is_whitespace_map = is_whitespace_map_spec.fetch_data()
total_whitespace_channels = is_whitespace_map.sum_all_layers()

is_in_region_map = region_map_spec.fetch_data()
plot = total_whitespace_channels.make_map(is_in_region_map=is_in_region_map)

plot.add_boundary_outlines(boundary=BoundaryContinentalUnitedStatesWithStateBoundaries())
plot.set_boundary_color('k')
plot.set_boundary_linewidth('1')

plot.save("Number of TVWS channels in the United States.png")
```

Save the plot
Important!

- WEST supports existing research
- Competition is good
Many exciting directions

• Expand supported regions ("only" US, Canada, and Australia today)

• More propagation models (F-curves today)

• More rulesets (e.g. DSA model rules)

• Applied to another band

• New economic models

• Integrated with the cloud
Questions?

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